Research Paper | Education | E-ISSN No : 2454-9916 | Volume : 10 | Issue : 4 | April 2024

UNDERSTANDING GROUNDWATER DEPLETION IN INDIA: ASSESSING RISK THRESHOLDS AND ANALYSING CAUSATIVE FACTORS

Vian Dhanda

Student

ABSTRACT

Although hidden below the Earth's surface, groundwater makes up 99% of Earth's liquid fresh water and plays an important role in the water cycle. Rivers, lakes and wetlands are surface manifestations of groundwater, exchanging flow with the groundwater reservoir that feeds them when they need water and takes some of their flow when surface water is in excess. Groundwater also controls many features on the Earth's surface. The depth of the water table is partly responsible for different plant species occupying different positions along the slopes from hill to valley, as only the drought-tolerant plants can live on dry hillsides and water-tolerant plants live near streams. Dissolution of carbonate rocks by flowing groundwater creates caves and sinkholes. In desert environments, groundwater discharge forms oases, which provide habitats for animals and plants. Groundwater provides drinking water entirely or in part for as much as 50% of the global population and accounts for 43% of all water used for irrigation. Worldwide, 2.5 billion people depend solely on groundwater resources to satisfy their basic daily water needs. The Earth's population of nearly 8 billion in 2020 is expected to reach 11 billion by 2100. Humans will have to learn to produce sufficient food without destroying the soil, water and climate. This has been called the greatest challenge humanity has faced. Sustainable management of groundwater is at the heart of the solution. Scientific understanding and proper management of groundwater is essential because groundwater can alleviate the problem if we seek its responsible use and replenishment. Modern scientific measurements show that many of the major aquifers (groundwater reservoirs) of the world are being depleted. Such depletion can lead to a decrease in stream flow, drying of springs or wetlands, loss of vegetation, water-level declines in wells, and land subsidence. Yet another threat to groundwater is pollution resulting from human activity, generating chemicals and wastes that have leaked into the subsurface. Pollution degrades the quality of groundwater and poses a threat to human and ecological health. As the human population grows, more demand will be placed on groundwater, a vast, but finite, resource. The need for understanding our groundwater systems and thoughtfully managing them within the constraints of the hydrologic cycle is greater than ever. In this paper, our primary objective is to examine the history of the water crisis in India, critical risk tipping points and delve into the analysis of how we arrived at the current state of groundwater depletion, exploring the specific conditions and factors that have led us here. Furthermore, we will project the trajectory of this situation and assess where we are headed. Most importantly, we will outline the vision for the future that we aim to craft, considering the well-being of the next generations and the sustainability of India's groundwater resources.

KEYWORDS: National Water Policy, Diverse Groundwater Systems, Public Distribution System, Global Water Partnership, Underground Aquifers, Risk Tipping Point

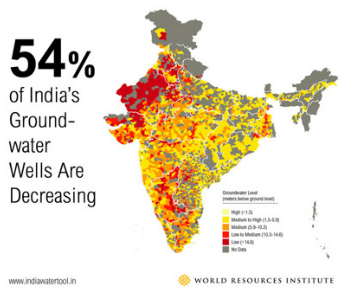
1. HISTORY OF WATER AS A RESOURCE IN INDIA

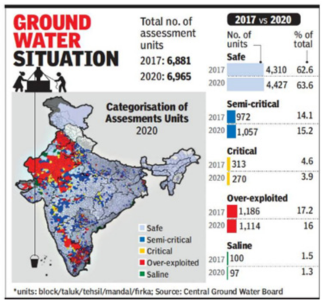
The history of the subject 'Irrigation & Power' dates back to 1855 when it was made the responsibility of the then newly created Department of Public Works. However, not much importance was given to irrigation work till the famine of 1858, when canal construction work started on an extensive scale and accordingly, an Inspector General of Canals was appointed. In 1863, it was decided to place this subject under the charge of an irrigation expert, with the designation of Inspector General of Irrigation under the administrative control of the Secretary of, the Public Works Department. In 1919, irrigation became a Provincial subject and the Government of India's responsibility was confined to advice, coordination and settlement of disputes over the rights to the water of Inter-Provincial rivers. The Public Works Department was merged with the Department of Industry in 1923. A combined department known as 'The Department of Industries and Labour looked after the subject of 'Irrigation and Power'. A Central Board of Irrigation was constituted in 1927. In 1937, the Department of Industry and Labour was bifurcated into the Department of Communication and the Department of Labour. The latter was assigned the work relating to Irrigation and Power.

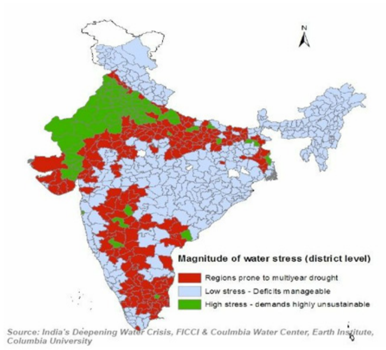
A separate Ministry of Irrigation and Power was set up in 1952 to look after the subject of irrigation. Further, the drought conditions in several parts of the country and the continued food shortages had brought into sharp focus the importance of providing greater irrigation facilities, and the need for preparing a comprehensive plan for future irrigation development in the country. In 1969, an Irrigation Commission was set up for future irrigation development programmes in the country in a comprehensive manner. In January 1980, the Department of Irrigation came under the new Ministry of Energy and Irrigation. In 1980, the then Ministry of Energy and Irrigation was bifurcated and the erstwhile Department of Irrigation was raised to the level of Ministry to have a coordinated and

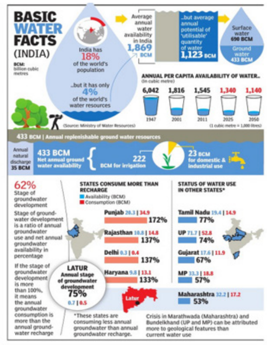
comprehensive view of the entire irrigation sector. In January 1985, the Ministry of Irrigation was once again combined under the Ministry of Irrigation and Power. However, in the re-organization of the Ministries of the Central Government in September 1985, the then Ministry of Irrigation and Power was bifurcated and the Department of Irrigation was re-constituted as the Ministry of Water Resources. This recognition of the necessity of planning for the development of the country's water resources in a coordinated manner resulted in a change in the character of the Ministry and the Ministry assumed a nodal role regarding all matters concerning the country's water resources. With the nomenclature of the Ministry as the Ministry of Water Resources, perspective planning was taken up to fulfil the role expected of the Ministry. In this new perspective, requiring overall planning and coordination of all aspects of the development of the country's water resources, it was felt necessary to formulate a National Water Policy, laying down, inter-alia, priorities for various uses of water. The National Water Resources Council (NWRC) was constituted and adopted the National Water Policy in September 1987 which was revised in 2002 and 2012. On the directions of the Hon'ble Supreme Court in 1996 passed in respect of Civil Writ Petition 4677/1985 for regulation and management of Ground Water in the country a Central Ground Water Authority was formulated. Presently, the Authority regulates States / UTs and issues NOC for groundwater abstraction by industrial, infrastructure and mining projects. [1]

include Karnataka, Bihar, Haryana, Gujarat and Maharashtra. Bundelkhand, which spreads across 13 districts of Uttar Pradesh and Madhya Pradesh, is among the regions worst hit by the crisis in India. The water table has shrunk in these areas and people are forced to walk miles to get a pitcher of water.









2. CRITICAL THRESHOLDS IN INDIA

India's groundwater situation is complex. The myopic view of groundwater, as posed through the national- and state-level aggregate picture, needs to be overcome through efforts at assessment of aquifers at the right scale. However, even the aggregated, national picture of groundwater resources reveals that the groundwater crises of depletion and contamination of India's aquifers are now evident across India's diverse groundwater systems. India constitutes around 16 per cent of the world's population, but the country has only four per cent of the world's freshwater resources. Changing weather patterns and recurring droughts, coupled with increasing pressure on groundwater resources due to over-reliance have made India one of the most water-stressed countries in the world. The official data from 2021 shows that more than 90 per cent of groundwater in India is used for irrigation in agriculture. The remaining 24 billion cubic meters supply about 85 per cent of the country's drinking water requirements. India is the largest extractor of groundwater in the world — more than the USA and China put together. At this rate of consumption, by 2025, large swaths of northwestern and southern India will have "critically low groundwater availability." The country is further projected to face severe water stress by 2050. As of 2019, only 17 per cent of the 191 million rural households in India had access to tap water connection. According to the Central Groundwater Board report (2017), nearly 40 per cent of the 700 districts in India have reported 'critical' or 'overexploited' groundwater levels. Uttar Pradesh and Madhya Pradesh — the two largest states in terms of area and population — are among around a dozen states where the magnitude of the water problem is not just large, but also complex. The other states facing the challenge

As groundwater is extracted faster than it can be replenished, the water table drops further and further away from the Earth's surface. This can become problematic, as wells are drilled or dug only to a certain depth. Eventually, people extracting groundwater from wells will soon face a risk tipping point when the water table in a given aquifer drops consistently below the well depth. At this point, the water will be inaccessible from the existing well infrastructure. This increases the risk that crops will be unable to be irrigated, forcing farmers to rely on other, often unreliable, sources of water. This also brings risks of the failure of food production systems that are reliant on groundwater for irrigation, with far-reaching consequences for consumers, people's livelihoods, nutrition and ecosystems. Nonetheless, this risk tipping point does not necessarily represent a final, irreversible point of no return in all cases. For example, it is not impossible for aquifers to sufficiently recharge and to be reachable again by existing infrastructure. For some shallow aquifers, it may take less than a decade for them to recharge naturally, while for others with different geological characteristics, it may take thousands of years [2] [Schreiner-McGraw and Ajami, 2021]. However, past the risk tipping point, only some people may have the capacity to cope by drilling deeper wells or supplement irrigation with other water sources, or to adapt by pursuing other livelihood options, but others will not.

3. HOW DID WE GET TO THIS CONDITION?

In the 1960s, India experienced food shortages and famine that led to the promotion of crop intensification. The government's national food procurement and distribution system, known as the Public Distribution System (PDS) ensures lower-income

households' access to food, but it also influences land-use patterns. Since government purchases guarantee a set income, farmers' decisions on which crops to plant have been influenced by the PDS's demand, motivating some farmers in locations with inadequate climatic and soil conditions to grow, for example, water-intensive crops such as rice [3] [Devineni and others, 2022], To keep costs to a minimum, the PDS purchases most crops from just a few provinces, such as Haryana and Punjab, where productivity rates of wheat and rice are the highest [4] [Ambast and others, 2006]. Together these provinces produce around 50 per cent of the country's rice supply and 85 per cent of its wheat stocks. However, particularly in the province of Punjab, where 98.9 per cent of cropland is irrigated by ground and surface water, 78 per cent of wells are considered overexploited [5] [Ministry of Jal Shakti, 2021] and the north-western region as a whole is predicted to experience critically low groundwater availability as soon as 2025.

3.1 Lack of Long-Term Foresight

According to the constitution of India, the responsibility for water resources development and management rests with individual states. Therefore, we can say that water governance in India is decentralized at the state level. Although the central government provides financial resources to the state governments for implementing national-level projects, the states are responsible for the development and management of water resources within their administrative/physical boundaries. States have different institutions such as regulatory authorities, water departments, gram panchayats, irrigation departments, and public works departments to develop and manage water resources. The upper state level is responsible for funding, policy-making, mobilization, and administration of the water sector in coordination with the central government. The state governments receive a significant chunk of their funding from the central government; therefore, they try to align their vision and policies with the central government. They make their policies and provide funding from their resources when necessary. The Indian constitution gives states full authority over water within their boundaries. At the state level, water is managed differently in rural and urban areas. In rural areas, water is managed through the Panchayat Raj system. The Panchayat Raj system consists of three administrative levels: Zilla (district) Panchayat at the top level, followed by Taluk (block) Panchayat at the middle level, and Gram (village) Panchayat at the bottom. At the Zilla and Taluk levels, the water bodies consist of both elected and appointed officials and at the Gram level, the water bodies include only elected representatives. Normally, a Gram Panchayat consists of about one to 10 villages, depending on the total population. This also varies from state to state. The Panchayat Raj system is responsible for the implementation, operations and maintenance, funding, and administration of water programs and projects. Functions involving funding and local policy-making are performed by Zilla and Taluk Panchayats, while functions such as implementation, monitoring, maintenance, and operations are performed by Taluk and Gram Panchayats [6] [Lindamood and others, 2017].

In urban areas, the water is managed by different political and bureaucratic bodies such as districts and municipalities where both elected and appointed officials perform their duties. These arrangements can differ from state to state. These district and municipality-level bodies are responsible for policy-making, implementation, and service provision. Service provision includes water infrastructure building and maintenance, water distribution, and other related tasks.

Civil society organizations such as non-governmental organizations (NGOs), academic bodies, community support organizations, and the general citizenry also contribute to water governance through consultation, research, funding, project design, and advocacy. Water utilities are underperforming in India despite investments to improve infrastructure and capacity. Most of the urban areas get water only a few hours a day, and the 24/7 water supply is still a far cry. A lack of adequate access to water has negative effects on gender equity as well, and women are primarily on the losing side because they are normally responsible for fetching water from afar. This takes a lot of their time and energy, severely harming their productivity. The piped water supply is heavily skewed in the favour of the rich. Most (65%) of the rich have access to piped water supply, while only 2% of the poor enjoy the same. In Delhi, 20% of the population gets 92% of the water, while the remaining 80% gets only 8% [5]. Poor water services along with sanitation are also blamed for the undernutrition of 40% of underweight children in India. India's rivers are also heavily polluted. According to studies, 70% of India's surface water is unfit for human consumption due to pollution.

India lags in water governance for a variety of reasons such as the poor capacity of Indian states, the complexity of the Indian decision-making system (which has several veto players), conflicts between states over water rights, and most importantly, the lack of water-related expertise among Indian political leaders and policymakers [7] [Araral and Ratra]. Water governance is taken as a concept broader than that of water management. Water management normally refers to the government making decisions to manage water systems. Water governance includes both internal and external processes through which societies manage their water resources. Jonathan Lautzea, Bunyod Holmatovb, Davison Sarucherac and Karen G. Villholtha in their research 'Conjunctive management of surface and groundwater in transboundary watercourses' [8] differentiated between water management and water governance as "Water governance is a set of processes and institutions through which management goals are identified and water management is charged with practical measures to achieve those goals. More simply water management aims to improve outcomes directly whereas water governance seeks to define those outcomes and align water management to achieve those goals". It is apparent from the argument that water governance encompasses water management as well. Water governance is a quite complex concept, and normally scholars define and understand it according to their core area of expertise. The Global Water Partnership (GWP) defines water governance as "the range of political, social, economic and administrative systems that are in place to regulate [the] development and management of water resources at different

levels of society". Pahl-Wostl [9] in her book

"Water Governance in the Face of Global Change from Understanding to Transformation" defined water governance as "the social function that regulates the development and management of water resources and provisions of water services at different levels of society and guiding the resources towards a desirable state and away from an undesirable state". According to the UN World Water Report (2006), the crisis of water is largely due to the failure of water governance, and for the sustainable development of water resources, water governance should be given priority. Water governance is defined and interpreted in a very broad manner. Recently, researchers have debated and brought many modern concepts within the water governance envelope: for example, Integrated Water Resource Management (IWRM) [10] and Adaptive Co-Management (ACM) [11]. Due to the failure of conventional water management, many responses have been developed to address the human and environmental problems related to water, and this has resulted in a dynamic shift in water governance incorporating human, ecological, and collaborative dimensions well within its boundaries.

3.2 Lack of Knowledge about water conservation

Groundwater, unlike surface water, is hidden underground, limiting human ability to foresee the changes that happen in these reservoirs. Most people have only a vague notion of how groundwater and aquifers work, which could lead to mismanagement [12] [Margat and Van der Gun, 2013]. In general terms, there tends to be little monitoring and few long-term observations of groundwater withdrawals, while recharge rates tend to be an estimate rather than consistently measured data. Groundwater monitoring is usually the responsibility of public institutions and in many places, the cost of developing, operating and maintaining a monitoring network is a constraining factor (UN Water, 2022). In other cases, the monitoring of groundwater withdrawals is not required by public authorities. Where there are in situ observations, they tend to be scattered and cover only a short period, limiting the development of predictive and large-scale models that can support management decisions [13] [Li-Yin Liu, Christopher Brough, Wei-Ning Wu 2022]. This lack of information means that often we do not know how much groundwater is available, which favours the practice of over-extraction since it makes sustainable water management efforts more difficult to develop.

3.3 Prioritising Profits

Groundwater is a type of common-pool resource, one with a relatively finite supply that is not owned by any one entity but rather shared by many. As discussed in the theory of "The Tragedy of the Commons," these resources are particularly susceptible to overexploitation and degradation [14] [Garrett Hardin Published in American Association for the Advancement of Science]. Individuals are free to take advantage of those resources for short-term gains that undermine the long-term sustainability of the resource for everyone since the costs of degradation or depletion are externalized and distributed among all users. Aquifers, for example, have relatively limited supply, and users are driven by a sense of competition to optimize individual benefit, motivated by the belief that others will not act in the best interest of the collective or without a long-term perspective in mind, which ultimately leads to a depletion of the aquifer over time.

3.4 Global Demand Pressure

A strong relationship between groundwater and international food supply chains is also driving groundwater depletion. Many of the products grown in countries that overdraft their groundwater resources are sold and consumed in places far away. The water required to produce a product is known as "virtual water" [15] [Chengyi Tu, Samir Suweis & Paolo D'Odorico 2019]. In this case, though the groundwater is not physically exported, it is traded in the form of virtual water used for irrigating crops. About 11 per cent of depleted groundwater is embedded in international crop trade in the form of virtual water, of which India exports around two-thirds [16] [Carole Dalin, Makoto Taniguchi and Timothy R. Green 2017].

3.5 Insufficient Risk Management

Groundwater tends to be perceived as a reliable and safe source of water, available independent of seasonal or climatic changes. Reaching it is not easy though; it comes at a cost for the farmers who have to pay for the equipment to dig a well and for the running cost of the electricity required to bring water out to the surface. To support farmers and reduce their running costs, some countries subsidize the energy cost of water pumping. While government subsidies of this nature are meant to ease affordability and accessibility to groundwater, they also increase the probability of over-extracting this valuable resource and decrease any incentive to diversify irrigation methods. In the case of India, energy subsidies, together with other factors, have been shown to drive groundwater depletion. In the aftermath of the previously mentioned food shortages, a series of government incentives aimed to increase the country's food supply, including a subsidy for electricity to pump water for irrigation [17] [N. Devineni, Shama Perveen, U. Lall, 2022], have contributed to the increase in the number of wells across India since the 1960s. Increased access to groundwater has allowed farmers to improve cropping intensity, as well as expand the number of cropping seasons in a year, by extending production into the predominantly dry winter and summer months. Following challenges to meter, bill, and collect payments in the use of electricity for groundwater pumping, most State Electricity Boards moved to flat tariffs in 1970, which reduced the cost of pumping for the farmers to virtually net zero. While the use of groundwater and production rates has grown over the years, the development of other irrigation alternatives like canals has lagged due to bureaucratic and design failures. Thus, though these programmes are well-intentioned, they increase the pressure and reliance on rapidly depleting groundwater resources, without setting up contingency plans in the event a risk tipping point is reached.

4. WHERE ARE WE HEADED? CURRENT AND FUTURE IMPACTS

4.1 Livelihood loss

Agriculture provides livelihoods for 2.5 billion people worldwide and is the largest source of income and jobs for

rural households (CBD, 2018). In India, agriculture and its associated sectors account for the largest source of livelihood (FAO, 1999), representing approximately 8 per cent of the world's population. Research shows that marginalized farmers are generally more likely to experience negative consequences when unable to reach groundwater, with empirical evidence from India showing only a small percentage of farmers were able to sustain agricultural production in their plots in such cases. In other cases, a dynamic of "chasing down the water table" by digging deeper wells was observed. This practice leads to the unprofitability of groundwater-dependent activities, due to high costs and lower groundwater yields, eventually leading to a full abandonment of these activities [18] [Richard Damania, Sébastien Desbureaux, Aude-Sophie Rodella, Jason Russ, and Esha Zaveri, 2023].

4.2 Migration / Displacement

Migration or displacement can occur because of groundwater depletion, primarily as people lose their livelihoods due to the impacts on agriculture. For example, evidence from India indicates that the abandonment of groundwater-dependent activities as a result of well failure has led to male labour migration to urban areas [18] [Rodella and others, 2023]. One study estimated that for every 30-metre increase in the depth of groundwater wells in Gujarat, India, there was a 2.5 per cent increase in the likelihood that a household had at least one migrant son. Most of the migration occurred from the dominant, land-owning caste, with less evidence of migration from agriculture within villages, perhaps due to education or financial barriers keeping certain farmers tied to agricultural livelihoods, even in the face of scarcity.

4.3 Loss of Safety

Depleting groundwater resources also represents the loss of a safety mechanism. Groundwater is widely considered a reliable water source that compensates for scarce surface water availability and little or unreliable rain [19] [M. Shamsudduha, Richard G T, 2022]. The groundwater depletion has caused many farmers to switch from groundwater irrigation to dryland farming that relies entirely on rainfall. However, the amount of rainfall the area gets is not enough to compensate for the loss of groundwater for irrigation, and thus, farmers must supplement this strategy with other water-saving techniques. Losing the security groundwater provides, relative to surface water resources, is a risk for both current and future generations. Depleting our groundwater resources now deprives future generations of the benefits and the safety past generations have enjoyed. Until now, groundwater has been a coping strategy for droughts, and it will likely become more important as the probability of drought events increases in the face of climate change.

4.4 Food and Water Insecurity

India would experience a substantial reduction in food production if the extraction of groundwater continues at the current unsustainable rate. Due to a constant decrease in water level, by 2050, the total carbohydrate-based food will be unavailable for almost 1/5th of the population. This sounds ominous, especially when the report predicts that by 2050, the base flow of Ganga will decrease by 38 per cent as compared to 2016. Climate change and the Himalayan glacial retreat make the future look catastrophic, raising questions about the existence of this river that sustains (providing both water and food) the densest and largest riverine population in the world over the years.

4.5 Ecosystem Damage and Bio-Diversity Loss

As mentioned before, groundwater depletion can affect different species living in underground aquifers, increasing the likelihood of Accelerating extinctions [20] [Stumpp and Hose, 2013]. Groundwater depletion can impact ecosystem functions and services beyond the aquifer itself: ecosystems on the surface, rivers and lakes are further threatened. For example, shallow groundwater sustains river baseflow and root-zone soil water in the absence of rain. Consequently, when groundwater supply is compromised, these fragile areas and their biodiversity are more susceptible during extreme dry periods [21] [Boulton and Hancock, 2006]. Furthermore, the impacts of groundwater depletion can directly affect wetlands' health to the point of degradation. This depletion affects the provisioning of services that are key for dependent communities.

5. THE FUTURE WE WANT TO CREATE

To assess solutions for avoiding risk tipping points, we must consider these key questions: Does the solution attempt to prevent negative system changes or target adaptation to them? Does the solution work within the current system or drive a fundamental reimagining of the system? Answering these questions is critical for understanding how different actions advance risk reduction goals and yield varied outcomes, including potential consequences and trade-offs. The solutions lie in four categories: Adapt-Delay, Adapt-Transform, Avoid-Delay, and Avoid-Transform.

5.1 Avoid

Avoid actions that alter the system to prevent crossing risk tipping points. Avoiding crossing a groundwater depletion risk tipping point requires a careful act of balancing groundwater withdrawals to aquifers' recharge rates. Notably, this does not mean we must stop using groundwater, but that we be mindful of the interconnected processes and systems reliant on this resource and ensure it is used sustainably. Thus, we need solutions that avoid the wasteful use of groundwater while also facilitating better recharge strategies. Some solutions can be as practical as fixing leakages in distribution systems, particularly those used for irrigation where the pipes are usually visible and leakages are comparatively easier to stop than in subsurface systems. Reducing the wasteful use of water can also be promoted with more efficient irrigation practices. Drip irrigation, for example, uses pipes and devices that act as drippers to deliver water directly to the soil near a plant's roots and in small amounts. When compared to other types of irrigation like overhead sprinklers, drip irrigation is more efficient at delivering water directly to the crops while wasting less water and hence is a commonly proposed alternative to save water. Alongside technologies like drip irrigation, improved irrigation scheduling can also contribute to reducing the amount of water applied to crops. Such alternatives include,

for example, evapotranspiration-based scheduling which can be done by consulting daily report services or by installing devices and controllers within the farm. Another option is soil moisture sensors to estimate the root-zone water availability. Farmers in Kansas and Texas who are part of the Ogallala Aquifer Program, meant to improve water management in the High Plains Aquifer, have seen a reduction of up to 15 per cent in irrigation water application during the last 10 years when using evapotranspiration-based irrigation scheduling. Increased irrigation water efficiency is generally a good practice but might come with a paradox. It has been observed that programmes meant to reduce water withdrawals may also bring outcomes like increasing irrigation area, as increased efficiency can cover more area with the same amount of water that was previously used, or can induce greater extractions, worsening depletion rates [22] [Lankford, 2023]. However, some also argue the irrigation efficiency paradox is a miscalculation and is inappropriately described from a hydrological perspective [22]. Another paradox might be emerging with the increased use of solar power to tap groundwater in places that have traditionally been out of reach due to high energy prices. Evidence suggests that solar-powered irrigation may lead to more groundwater drawdown, both in the long and the short term. Attention must be brought to these issues, as well-intended policies might turn out to cause long-term harm, especially when groundwater volume changes are difficult to observe and monitor, and are poorly regulated. In addition to improving irrigation efficiency to avoid wasteful use and conserve as much groundwater as possible, we can also act to boost the available groundwater resources by facilitating aquifer recharge. For example, interventions, such as restoring wetlands that enhance water infiltration to the subsurface, can enhance natural aquifer recharge while also protecting an endangered ecosystem. Other ways to enhance natural infiltration include collecting rain and stormwater that can be diverted to well-draining soils, small-scale river damming or artificial streams and ponds. All these options can contribute to subsurface water infiltration, while they also can be used directly for irrigation.

These options are better suited for shallow aquifers which have faster recharge rates, as not all aquifers are the same, and some take longer than others to recharge. Shallow aquifers may recharge within a decade and for others, it can take thousands of years. Some aquifers have not seen the addition of a drop of water since the beginning of the Holocene – approximately 12,000 years before the present [23] [Marc F P Bierkens and Yoshihide Wada, 2019]. For confined aquifers, located beneath a layer of material that is impermeable and prevents water from penetrating through the surface, another recharge option, known as deep injection, is possible. Deep injection consists of putting water directly into the aquifer using wells and sourcing it from rainwater, stormwater or treated wastewater. Importantly, recharge options can be helpful to address groundwater depletion either before or after crossing the risk tipping point, but they become critical closer to that point of inflexion. Additionally, enhancing groundwater monitoring can help inform and better water management practices. Satellite observations, for example, have often been used to overcome the information gap and to study wider land areas. Gravity Recovery and Climate Experiment (GRACE) measures changes in groundwater storage masses to create a more comprehensive picture of groundwater availability. From an individual perspective, chasing the water table down by digging deeper wells could be considered a temporary solution to address groundwater depletion. However, from a long-term perspective and considering that groundwater is a shared resource, it would contribute to the groundwater depletion risk tipping point. Digging deeper wells could be feasible for farmers with the available capital resources for a costly investment but for less wealthy farmers this is not possible [24] [Jasechko and Perrone, 2021]. From a common-pool perspective, one farmer's over-extraction of groundwater from a depleting aquifer has consequences on the others and deepens the risk of inaccessibility to the resource. Even if the aquifer were to recharge within a reasonable time, the farmers profiting from a depleting aquifer would be contributing to bringing the water table further down, not allowing for the possibility of the water table to recharge to a more easily accessible level. Additionally, in some cases, the characteristics of the aquifer make it unfeasible, including, in some instances, very low yields at deeper depths [24]

5.2 Adapt

Adapt actions reduce exposure to post-tipping point impacts and prepare for sustainable living within the new system. Adapting to groundwater depletion can be done in several ways, but the extent to which these are implemented in a way that promotes a more sustainable living is a matter of choice. Past the risk tipping point, people will have to adapt to less water availability with an array of impacts on their lives. For instance, utilizing alternative water sources to groundwater for irrigation can relieve the pressure on aquifers. This, if applied simultaneously with other solutions, could potentially contribute to the gradual process of avoiding crossing the risk tipping point, but could also help people to adapt to groundwater disappearance. Treated grey, black and desalinized water can also be used for crop irrigation and non-potable domestic uses. Grey water, for example, is used water that comes from sinks, washing machines, bathtubs and showers and represents a varying but significant portion of around 70 per cent of household outputs [25] [Michael Oteng-Peprah & Mike Agbesi Acheampong & Nanne K. deVries, 2018]. Grey water for irrigation requires little treatment and is a relatively inexpensive supplementary source of water for irrigation. Black wastewater, on the other hand, contains toxic chemicals or excrement requires specialized treatment, and is thus very costly. Similarly, desalinating water with varying salt content is also an expensive alternative usually afforded only by richer nations. Additionally, the desalination process is energy intensive and, if fuelled by a non-renewable source, further contributes to greenhouse gas emissions [26] [Argyris Panagopoulos, Katherine-Joanne Haralambous 2020]. Also, some outputs of the process are toxic, and if handled inappropriately, can cause environmental harm. Overall, attention should be drawn to the potential negative consequences of using treated wastewater or desalinized water for irrigation as it could cause nutrient soil imbalances and contamination, as well as the potential emergence of exposure to pathogens and other contaminants.

Other alternatives include improved agricultural practices, including farming techniques suited for arid and semi-arid places. For instance, in the farming community of Garden City, Kansas, a growing group of farmers have chosen to develop a "dryland farming" system that reduces or even eliminates groundwater use This group of farmers is a minority among the neighbouring farmlands as a majority have continued and even increased the number of wells despite being aware that parts of the High Plains aquifers are in danger of depletion. Dryland farming is a special case of rain-fed agriculture practised in arid and semi-arid regions in which farming practices emphasize water conservation throughout the year. The system focuses on retaining the precipitation in the land, reducing evaporation from the soil and utilizing drought-tolerant crops that grow during periods that best-fit precipitation patterns. This system allows farmers in Garden City to grow wheat and sorghum, but not corn, which tends to be a more lucrative crop. Nonetheless, for some farmers, the benefit dryland farming represents to protecting groundwater resources outweighs economic profit. Water harvesting is another alternative source of water that can be used for irrigation. Rainwater harvesting, for example, collects rainwater when it is available and stores it for later use. This method can be used at even very small scales to water subsistence agriculture, contributing to food security. An innovative solution for water harvesting is the collection of dew and fog. A fog collector is a simple frame that supports a section of mesh; the water content in the air condenses on the surface of the collector, forming water droplets that drip into a gutter that goes to a reservoir. The system is inexpensive and fog water can be delivered to drip irrigation systems, but it requires very specific climatologic and topographic conditions, and yields are difficult to predict. Some places will have options that are unavailable to others, either due to climatological conditions or resource availability. For instance, rainwater or fog harvesting is not readily available in Saudi Arabia as the arid nation receives very little precipitation. As a solution, Saudi Arabia more strongly relies on treated wastewater for irrigation and desalinated seawater for urban needs to preserve the remaining groundwater and to make sure all water needs are met. These technologies are, however, often very expensive and thus may not be an available alternative for other regions.

5.3 From Delay to Transform

Our trajectory towards groundwater depletion is driven mainly by the fact that we are extracting water from aquifers at a much faster rate than they can be recharged. Since the root causes of the problem are so diverse, it will require an equally diverse set of solutions to address the problem as a whole. Importantly, different interventions applied together as a package are more likely to delay crossing the tipping point than just a single action. Solutions to delay crossing the tipping point include technological options to improve water use in irrigation, and managed aquifer recharge, along with improved rules and regulations. More can be done on this last point to transform how society values, uses and manages groundwater. To move away from a groundwater depletion risk tipping point, we must establish a shared understanding of what constitutes the sustainable use of groundwater with an understanding that being on a finite planet means resources are already limited, and as we disrupt natural systems, we face scarcity and competition in meeting human needs. We need to establish new definitions of sustainability and resilience for our groundwater resources to balance availability and needs, considering all the users of the resource and ensuring that they are not excluded simply because of the actions of a few. Transforming our systems to ensure cooperation and trust on all scales is necessary to facilitate these solutions. Additionally, how we value natural resources and choose to use them matters. Regulations and policies are written and implemented by people, and the values we choose to prioritize are reflected in the tools used for decision-making. As such, we need to transform our systems to take natural systems into account in planning, to see the groundwater system and human societies as part of an interconnected whole that relies on natural processes to survive. For instance, water policies should incorporate environmental considerations to ensure there is enough water for both surface and subsurface ecosystems to stay healthy. For this policy, changes are required and should include establishing optimal paths for groundwater extractions with a true consideration of ecosystem dynamics and functional health. Sustainability can be applied weakly or strongly as it is a matter of values and choices. The continued extraction of depleted groundwater resources could be justified, for instance, by arguing it enables socioeconomic growth or that if done for a short period, it can provide prosperity to adapt socioeconomic structures to a sustainable future [27] [Aeschbach-Hertig and Gleeson, 2012]. Indeed, there are ways to sustainably use groundwater, but unfortunately, the observed tendency is the prioritization of profits or economic capital, rather than that of social and environmental aspects. Strong sustainable policies on groundwater extraction must be implemented to reduce its systemic use where depletion is prevalent, while management strategies should ensure current and future generations can benefit from the safety this resource can provide [27]. This can only occur by adopting a vision and consideration for the future, to ensure that there is enough groundwater for future generations to use. Change comes either by disaster or by design, and we can choose our present conditions that have implications for the future of our generations. We must choose a just pathway that ensures access to groundwater for all.

6. CONCLUSION

We are rapidly approaching groundwater depletion risk tipping points globally, with serious potential impacts on local livelihoods and global food security. Our actions and behaviours, such as prioritizing profits and insufficient risk management, have brought us to collapse. However, reaching a risk tipping point for groundwater depletion is not inevitable, and even some places that have crossed the threshold could be brought back. We have the benefit of seeing the risk tipping point ahead of us and can choose to take action, to sustainably balance the way we use our groundwater resources by understanding how these systems work. We can act to ensure that our societies, food security and ecosystems are resilient and sustainable, both in the present and the future.

REFERENCES

1. Department of Water Resources, River Development and Ganga Rejuvenation Introduction | Department of Water Resources,

River Development and Ganga Rejuvenation | India (jalshakti-dowr.gov.in)

2. A. Schreiner-McGraw, H. Ajami Published in Journal of Hydrology 2021
3. N. Devineni, Shama Perveen, U. Lall Published in Nature Communications 2022
4. S.K. Ambast Agricultural Water Management 82(3):279-296 February 2006
5. Ministry of Jal Shakti, 2021
6. Danielle Lindamood University of Waterloo degree of Masters of Environmental Studies in Sustainability Management
7. E. Araral, S. Ratra Published 2016, Environmental Science, Law Water Policy
8. Jonathan Lautzea, Bunyod Holmatovb, Davison Sarucherac and Karen G. Villholtha Conjunctive management of surface and groundwater in transboundary watercourses
9. Pahl-Wostl's [9] book on Water Governance in the face of global change from Understanding to Transformation
10. https://www.un.org/waterforlifedecade/iwrm.shtml
11. Claudia Pahl-Wostl Adaptive and Integrated Water Management 2008 DOI:10.1007/978-3-540-75941-6_4
12. Margat and Van der Gun, 2013 Groundwater around the World: A Geographic Synopsis 2013 DOI:10.1201/b13977
13. Li-Yin Liu, Christopher Brough, Wei-Ning Wu 'When water conservation matters: Examining how water scarcity experiences create windows of opportunity for effective water-saving policy initiatives' Published in Environmental Science 2022
14. Garrett Hardin The Tragedy of the Commons Source: Science, New Series, Vol. 162, No. 3859 (1968), Published in American Association for the Advancement of Science
15. Chengyi Tu, Samir Suweis & Paolo D'Odorico Impact of globalization on the resilience and sustainability of natural resources
16. Carole Dalin Makoto Taniguchi and Timothy R. Green Unsustainable groundwater use for global food production and related international trade Published online by Cambridge University Press: 02 July 2019
17. N. Devineni, Shama Perveen, U. Lall Solving groundwater depletion in India while achieving food security Published in Nature Communications 13 June 2022
18. Richard Damania, Sébastien Desbureaux, Aude-Sophie Rodella, Jason Russ, and Esha Zaveri Quality Unknown: The Invisible Water Crisis
19. M. Shamsudduha, Richard G T Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin
20. Stumpp and Hose The Impact of Water Table Drawdown and Drying on Subterranean Aquatic Fauna in In-Vitro Experiments
21. A. Boulton, P. Hancock Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications
22. Bruce A. Lankford Resolving the paradoxes of irrigation efficiency: Irrigated systems accounting analyses depletion-based water conservation for reallocation
23. Marc F P Bierkens and Yoshihide Wada Non-renewable groundwater use and groundwater depletion: a review
24. Scott Jasechko, Debra Perrone Global groundwater wells at risk of running dry.
25. Michael Oteng-Peprah & Mike Agbesi Acheampong & Nanne K. deVries Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review
26. Argyris Panagopoulos, Katherine-Joanne Haralambous Environmental impacts of desalination and brine treatment - Challenges and mitigation measures
27. Werner Aeschbach, Tom Gleeson Regional strategies for the accelerating global problem of groundwater depletion